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E.J. Anthony*, D.L. Desai** and F.D. Freidrich*

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FLUIDIZED BED COMBUSTION OF DEVCO PRINCE TEST REJECTS

by

E.J. Anthony*, D.L. Desai** and F.D. Freidrich*

ABSTRACT

At present 6 to 7 million tons of washery rejects are generated in Canada annually. For some time the Energy Research Laboratories (ERL) of CANMET has been interested in finding methods of utilizing this material, one such method being Atmospheric Fluidized Bed Combustion (AFBC). To this end ERL's Combustion and Carbonization Research Laboratory (CCRL) has already carried out a number of experimental and design studies on the use of western coal rejects.

Continuing this work, CCRL obtained several tons of a specially produced reject from Devco Prince Coal for combustion trials. The rejects were prepared from a batch of raw coal, at the Electric Power Research Institute's (EPRI) coal cleaning test facility near Homer City, Pennsylvania. Unfortunately, the cleaning process produced a reject stream whose properties were similar to those of the parent raw coal. Nevertheless 11 tests were carried out on this material in CCRL's pilot scale AFBC test rig. All but two of the trials were carried out with limestone addition. The tests were run at a nominal bed temperature of 850°C, two fluidizing velocities (1.2, 2.4 m/s), and an excess oxygen level of 3.6%. Test were performed both with and without fly ash recycle.

Results were in good agreement with previous work, with sulphur captures of over 90% being achieved with Ca/S molar ratios around 3 in conjunction with fly ash recycle. Emissions of NO_x were below the 258 ng/J limit, ranging from 130 to 190 ng/J. CO emissions without fly ash recycle were lower

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*Research Scientist and **Research Engineer, Combustion and Carbonization Research Laborataory, Energy Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, K1A 0G1

than those seen with the clean coal, with concentrations as low as 45 ppm being achieved. Further work is necessary using rejects with higher ash content before general conclusions about the difference between clean coal and the rejects can be made.

COMBUSTION EN LIT FLUIDISÉ DE REBUTS PROVENANT DE LA DEVCO PRINCE

par

E.J. Anthony*, D.L. Desai** et F.D. Freidrich*

RÉSUMÉ

À l'heure actuelle, de six à sept millions de tonnes de liquides résiduels sont produits chaque année au Canada. Depuis quelques temps déjà, les Laboratoires de recherche sur l'énergie (ERL), de CANMET, cherchent à trouver des méthodes permettant de réutiliser ces matériaux de rebut. La combustion en lit fluidisé à la pression atmosphérique (CLFPA) est l'une de ces méthodes. Le Laboratoire de recherche sur la combustion et la carbonisation (LRE) a mené des essais et fait des études sur l'utilisation des rebuts dérivés du charbon de l'Ouest.

Poursuivant ses recherches, le LRCC a obtenu de la Devco Prince Coal plusieurs tonnes de matériaux de rebut produits spécialement à des fins d'essai de combustion. Les rebuts ont été préparés à partir d'une petite quantité de charbon non lavé, à la laverie expérimentale de l'Electric Power Research Institute (EPRI), situé près de Homer City, en Pennsylvanie. Malheureusement, le lavage a donné un produit en circulation dont les propriétés étaient semblables à celles du charbon brut original. Toutefois, ces matériaux de rebut ont été soumis à 11 essais à l'installation expérimentale de CLFPA de LRCC. Des additifs de calcaire ont été ajoutés pour tous les essais à l'exclusion de deux. La température nominale du lit pendant les essais était de 850°C. Les opérations se sont déroulées à deux vitesses de fluidisation (1,2, 2,4 m/s) avec un taux additionnel d'oxygène de 3,6 %. Les essais ont été effectués de deux manières; avec recyclage des cendres volantes et sans recyclage des cendres volantes.

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*Chercheur scientifique et **Ingénieur de la recherche, Laboratoire de recherche sur la combustion et la carbonisation, Laboratoires de recherche sur l'énergie, CANMET, Énergie, Mines et Ressources Canada, Ottawa, K1A 0G1

Les résultats concordaient avec ceux découlant des études précédentes, la capture de soufre étant supérieure à 90 % et les rapports molaires Ca/s étant d'environ 3, en même temps que s'effectuait le recyclage des cendres volantes. Les émissions de NO_x étaient inférieures à la limite de 258 ng/J, variant de 130 à 190 ng/J. Les émissions de CO sans recyclage des cendres volantes étaient inférieures à celles qui sont produites par la combustion du charbon lavé et des concentrations aussi faibles que 45 ppm ont été obtenues. On devra poursuivre les recherches en utilisant des rebuts ayant une teneur en cendres volantes plus élevée avant d'être en mesure d'établir de façon définitive la différence entre le charbon lavé et les matériaux de rebut.

INTRODUCTION

Following work on western coal washery rejects (1,2), a number of trials were carried out at CCRL on coal rejects from Devco Prince coal. The test rejects were prepared from a batch of raw coal sent to EPRI's coal cleaning test facility near Homer City, Pennsylvania. Unfortunately, the reject stream of the coal cleaning process, had properties similar to the parent coal. Nevertheless 11 tests were carried out to gain some insight into the behaviour of these washery rejects.

The coal tested was deep mined at Cape Breton Development Corporation's Prince Mine located at Point Aconi, Nova Scotia. It is ranked as a high volatile A bituminous by ASTM D-388 and had an average sulphur content of 5.2%. Its ultimate and proximate analysis together with other analytical details are given in Table 1.

Table 2 gives the ash composition, ash fusion temperatures and the free swelling index of the coal.

Table 1 - Analysis of Devco Prince test rejects

Proximate Analysis	As Received (weight per cent)	Air Dried (weight per cent)
Moisture	7.85	0.0
Ash	21.01	22.80
Volatile matter	29.44	31.95
Fixed	41.70	45.26

Ultimate Analysis	Air Dried (weight per cent)
Carbon	60.78
Hydrogen	4.16
Sulphur	5.18
Nitrogen	1.34
Ash	22.80
Oxygen (by difference)	5.75
Chlorine	0.26
Heating Value	24.10 MJ/kg

Sulphur Forms	As Received (weight per cent)	Air Dried (weight per cent)
Sulphate	0.53	0.57
Pyritic	3.28	3.55
Organic	1.13	1.23

Table 2 - Ash Composition, fusibility and free swelling index

Composition	Weight per cent
SiO_2	45.49
Al_2O_3	21.92
Fe_2O_3	24.78
TiO_2	0.80
P_2O_5	0.04
CaO	1.82
MgO	0.81
Na_2O	0.48
K_2O	1.92
BaO	-
SrO	0.01
MnO_2	-
LOF	0.75
Oxidizing	Temp (°C)
Initial Deformation	1371
Softening spherical	1398
Softening hemispherical	1412
Fluid	1428
Reducing	Temp (°C)
Initial Deformation	1099
Softening spherical	1244
Softening hemispherical	1300
Fluid	1408
Free swelling index	3.5

A 6.3 mm x 0 limestone from Havelock, New Brunswick was used for all tests. It contained about 95% $CaCO_3$ and in previous work was found to be a moderately effective sulphur sorbent (3). An analysis of the limestone is given in Table 3.

Table 3 - Analytical Data for Havelock limestone

Elemental analysis of Havelock limestone

Component	As Element (weight per cent)	As Oxide (weight per cent)
Loss on Ignition at 980°C	42.6	
Si (SiO_2)	0.6	(1.4)
Al (Al_2O_3)	0.1	(0.2)
Fe (Fe_2O_3)	0.1	(0.2)
Ca (CaO)	39.5	(55.3)
Mg (MgO)	0.1	(0.7)
S	0.0	(0.0)

During these tests, the initial bed material was "brown sand" which had a mean size of 1 mm, a particle density of 2580 kg/m^3 and a bulk density of 1570 kg/m^3. A fresh charge of 110 kg was used for each run. This meant that no attempt was made to achieve a limestone bed since the turnover time varied from 4 to 14 h while the duration of the trials after thermal equilibrium had been achieved was typically 4 to 8 h. In one case a run was carried out for 24 h but after 12 h the conditions were changed. Instead, profiles of emissions of SO_2, CO and NO_x were examined and an effective "steady state" was assumed when those profiles became asymptotic. Although this approach is not ideal, it gave a worst case for SO_2 emissions, while other bed parameters such as CO, NO_x emissions and combustion efficiency may reasonably be expected to achieve "steady state" in a much shorter period.

THE PILOT SCALE COMBUSTOR

The major components of the AFBC rig, shown in Fig. 1, have been described in a separate report (4).

The combustor stands about 4.8 m high and has external dimensions of 0.98 x 0.97 m. The internal dimensions are 380 x 406 mm giving a bed area of 0.155 m^2. The bed, which is lined with firebrick and insulating refractory, is instrumented with thermocouples and pressure probes. In addition there are inserts on two opposite faces of the bed to allow up to 48 water cooled tubes to pass through it. In this study the maximum number of tubes used was 16.

The air distributor consists of 9.5 mm thick mild steel plate fitted with a 100 bubble caps to allow even distribution of the fluidizing air. The 32 x 13 mm diameter stainless steel bubble caps are arranged in a 35 x 38 mm rectangular pitch. The design of the bubble caps, which are made of bolts drilled with a 6 mm hole through their central axis and four 3 mm holes just below the head of the bolt, prevents "weeping" of bed solids into the plenum chamber and causes air to egress horizontally. A 20 mm gap between the distributor plate and the bolt head provides a stagnant layer of sand which prevents warping of the distributor plate.

The fuel system consists of a coal and a limestone hopper which feed into an air lock valve via weigh feed belts. A variable speed water-cooled screw at the bottom of the combustor was connected by a flexible fiberglass hose to the air lock valve and delivered the coal and limestone directly into the bed.

A multi-cyclone was connected in series to the freeboard by a water cooled stainless steel duct. The cyclone products could either be collected to a drum for non recycle tests or pneumatically reinjected into the bed for ash recycle tests.

The on-line instrumentation consisted of Non Dispersive Infra-Red (NDIR) gas analyzers for CO, CO_2 and SO_2 concentrations, a paramagnetic O_2 analyzer, a chemiluminescent NO_x analyzer and a UV analyzer for SO_2 which served as cross check on the NDIR SO_2 analyzer. The temperatures in the bed, freeboard and cooling circuits were measured by "K" type thermocouples and the pressure drop across the bed was measured by means of a pressure transducer connected to a scanning valve. All data were recorded on a floppy disk system via a process controller and desk top computer every 5 minutes. In addition, all data were recorded every 2 minutes on a data logging system which served as a backup system.

THE TEST PROGRAM AND PROCEDURE

The combustor was raised to a temperature of about 600°C before coal was introduced. As soon as the desired bed temperature of 850°C was achieved,

the fluidizing velocity was adjusted to its final value and limestone was introduced at the desired Ca/S molar ratio. When thermal equilibrium was achieved in the combustor, the data logger was turned on and gas concentrations were monitored continuously, with minor adjustments being made to the bed cooling rate and fluidizing velocity to maintain stable operating conditions. The combustor was run for at least one hour after the CO, NO_x and SO_2 concentrations stabilized to provide "steady state" data.

Table 4 gives feed rates and bed conditions for the "steady state" data from the 11 combustion trials that were carried out. Table 5 gives the gas compositions and sulphur capture at "steady state". Because the program written for data acquisition only allows storage of 12 h of data and requires data storage to recommence under a different file number, the fifth run is divided into two, run 5 and 5A. In addition the fluidizing velocity was lowered to 1.22 m/s for this second segment. Partial defluidization occurred after only 4 h during this second period and the velocity had to be increased again to prevent this phenomena from proceeding, thus run 5 and 5A may be regarded as separate runs.

Table 4 - Steady state run conditions

Test Number	Dry Coal Feed Rate kg/h	Sorbent Feed Rate kg/h	Fluidizing Air m^3/h	Recycle Air m^3/h	Fluidizing Velocity m/s	Bed Temp. °C
PRB1	45.77	0.0	336.5	0.0	2.45	855
PRB2	42.44	0.0	306.0	29.54	2.42	841
PR1	21.84	10.56	150.2	23.31	1.26	841
PR2	21.74	11.51	154.4	29.64	1.33	844
PR3	41.54	21.01	269.7	59.28	2.40	846
PR4	41.98	25.81	259.4	69.11	2.39	852
PR5	41.99	21.03	279.2	61.42	2.45	851
PR5A	41.77	29.43	269.7	48.33	1.84	824
PR6	43.83	34.06	317.9	0.0	2.33	852
PR7	31.22	14.12	183.4	67.98	1.83	850
PR8	31.21	17.69	180.7	65.92	1.78	841
PR9	26.33	20.68	215.0	0.0	1.56	850

Table 5 - Gas compositions and sulphur capture data

Test Number	O_2 %	CO_2 %	NO_x ppm	CO ppm	SO_2 ppm UV	SO_2 ppm IR	Ca/S	S'cap %	S cap %
PRB1	4.6	13.0	478	387	4586	4729	0.00	11.9	9.1
PRB2	3.5	13.5	415	795	4438	4368	0.00	8.3	9.7
PR1	3.4	15.2	426	663	652	670	2.84	86.5	86.1
PR2	4.2	14.2	441	448	241	268	3.11	94.7	94.1
PR3	3.5	14.8	345	757	957	892	2.97	80.2	81.5
PR4	3.1	15.8	325	879	228	259	3.61	95.3	94.7
PR5	4.1	14.0	333	689	859	919	2.94	82.0	80.5
PR5A	3.9	14.1	357	1897	1220	1324	4.13	75.7	73.6
PR6	4.0	15.0	404	46	719	801	4.56	86.4	84.8
PR7	2.9	14.8	339	609	607	633	2.65	87.2	86.7
PR8	3.5	15.4	341	549	352	367	3.33	92.7	92.4
PR9	5.6	14.0	442	45	622	699	4.61	86.7	85.1

S'cap refers to results based on the UV measurements of SO_2

S cap refers to results based on the IR measurements of SO_2

CO EMISSIONS

The CO emissions were relatively low except for run PR5A which corresponded to a relatively low bed temperature of 824°C. In general these results were consistant with results obtained from previous work on Devco Prince coal (5). Two of the results show very low CO concentrations (i.e., PR6 and PR9 at 45 ppm). The single obvious difference between these trials and almost all the others was the absence of recycle air. It may also be significant that the base line test without recycle, PRB1 had half the CO emissions of run PRB2 (387 ppm compared with 795 ppm). This effect was not observed in the earlier work with the parent coal.

The results show that bed temperature influenced CO emissions. A 25°C drop from the nominal 850°C test condition was associated with a two fold increase over the highest reading obtained with any of the other tests. Fly ash recycle also significantly increased CO emissions. Increasing the fluidizing velocity also caused an increase in CO, but this effect is smaller than

the other two effects, over the range of velocities examined (1.3 to 2.5 m/s). Figure 2 shows CO emissions as a function of fluidizing velocities and Figure 3 shows combustion efficiency versus CO emissions. A clear trend is indicated by the runs performed with recycle air with increasing CO as the combustion efficiency falls. However, the data points for the three runs without recycle air behave quite differently, but the reasons for this are not clear.

NOx EMISSIONS

NO_x emissions which ranged from 330 to 480 ppm or 130 to 180 ng/J, were well within the emission guidelines of 258 ng/J (6). Unlike the results for CO, there was little effect on the emission levels due to variations in bed temperature and fluidizing velocity. The NO_x levels were on average slightly lower for tests with fly ash recycle. In general these results are similar to those observed with the cleaned coal (5).

SULPHUR CAPTURE

Baseline tests without sorbent indicate a capture of about 10%, which corresponds to emission of about 4500 ppm or 3800 ng/J. This was well above the emission guidelines of 705 ng/J. For tests with limestone addition, a sulphur capture of up to 95% was achieved with a Ca/S molar ratio of 3.6; this corresponded to emissions as low as 228 ppm or 200 ng/J. The results from the UV analyzer were quoted in the text because they were judged to be more reliable than those from the IR instrument. Table 6 gives the SO_2 emissions in terms of ng/J, together with the limestone utilization.

With the exception of run 5A, where partial defluidization occurred, the behaviour of the limestone is remarkably uniform, with limestone utilizations of about 30% and 18%, with and without fly ash recycle respectively. The change in fluidizing velocity did not seem to significantly effect limestone utilization. These results are comparable with the results obtained with the parent coal and Havelock limestone, where limestone utilization varied from 13 to 24% without fly ash recycle and 19 to 46% with fly ash recycle. The results clearly indicate that emission guidelines can be met without difficulty using Ca/S molar ratios typical of normal AFBC operation.

Table 6 - SO_2 Emissions and limestone utilization

Test Number	SO_2 Emissions (UV) ng/J	SO_2 Emissions (IR) ng/J	Limestone Utilization (UV) %	Limestone Utilization (IR) %
PRB1	3789	3907	-	-
PRB2	3943	3881	-	-
PR1	582	582	30.5	30.3
PR2	229	225	30.5	30.3
PR3	852	794	27.0	27.4
PR4	200	228	26.4	26.2
PR5	783	838	27.9	27.4
PR5A	1044	1133	18.3	17.8
PR6	584	653	18.9	18.6
PR7	549	573	32.9	32.7
PR8	313	326	27.8	27.7
PR9	571	641	18.8	18.5

COMBUSTION EFFICIENCY

Carbon combustion efficiencies, given in Table 7, show carbon losses ranging from 1.3% to 3.8% and 0.5% to 2.5% with and without fly ash recycle respectively. The parent coal showed carbon losses ranging from 0.3% to 3.8% and 0.6% to 9.4% with and without fly ash recycle respectively. The data do not show the same strong effect of fly ash recycle as seen with the parent coal. The lower values for carbon loss for tests without recycle can be partially attributed to lower fluidizing velocities, 2.5 compared to 3 m/s. Based on a limited number of observations, the combustion performance without recycle appeared to be somewhat better than that for the parent coal, whereas the results for recycle seem to be comparable.

Table 7 - Carbon Combustion Efficiency

Test No.	PRB1	PRB2	PR1	PR2	PR3	PR4	PR5	PR5A	PR6	PR7	PR8	PR9
Comb. Effic. %	99.5	97.9	98.0	98.2	97.2	97.2	96.2	96.2	98.2	98.0	98.7	97.6

CONCLUSIONS

Devco Prince coal rejects were burnt in an AFBC pilot scale rig. Due to the cleaning process involved the test rejects had an ash content of 22.8% which was only slightly higher than the parent coal (typically around 18% ash). Consequently the combustion performance of the rejects was similar to that of the parent coal. Some differences however were noticed. For instance, the carbon combustion efficiency without fly ash recycle ranged from 98.2 to 99.5% compared with 94.2 to 99.7% for similar conditions when using the parent coal. The limestone utilization however appeared to be only marginally different than tests with the parent coal and Havelock limestone. One interesting result is that the uncontrolled sulphur capture for the baseline tests did not appear to change significantly despite the higher ash content of the rejects. It was around 10% for both test series.

CO emissions, which were comparable with the test work done on the parent coal, were relatively low ranging from 450 to 880 ppm for tests with fly ash recycle. For tests without fly ash recycle they ranged from 45 to 380 ppm. This effect of recycle on CO emissions was not observed during earlier work on the parent coal and deserves further investigation since it is based on a limited number of observations. NO_x levels were comparable with earlier work ranging from 320 to 480 ppm or 130 to 190 ng/J, which is well within the limit of 258 ng/J.

Uncontrolled emissions of SO_2 with this fuel were around 4500 ppm or 3800 ng/J, making it necessary to use a sulphur sorbent. A sulphur capture of over 90% could be achieved with a Ca/S molar ratio of 3 and it was possible to meet emission guidelines of 705 ng/J or the stricter limit for larger boilers of 258 ng/J.

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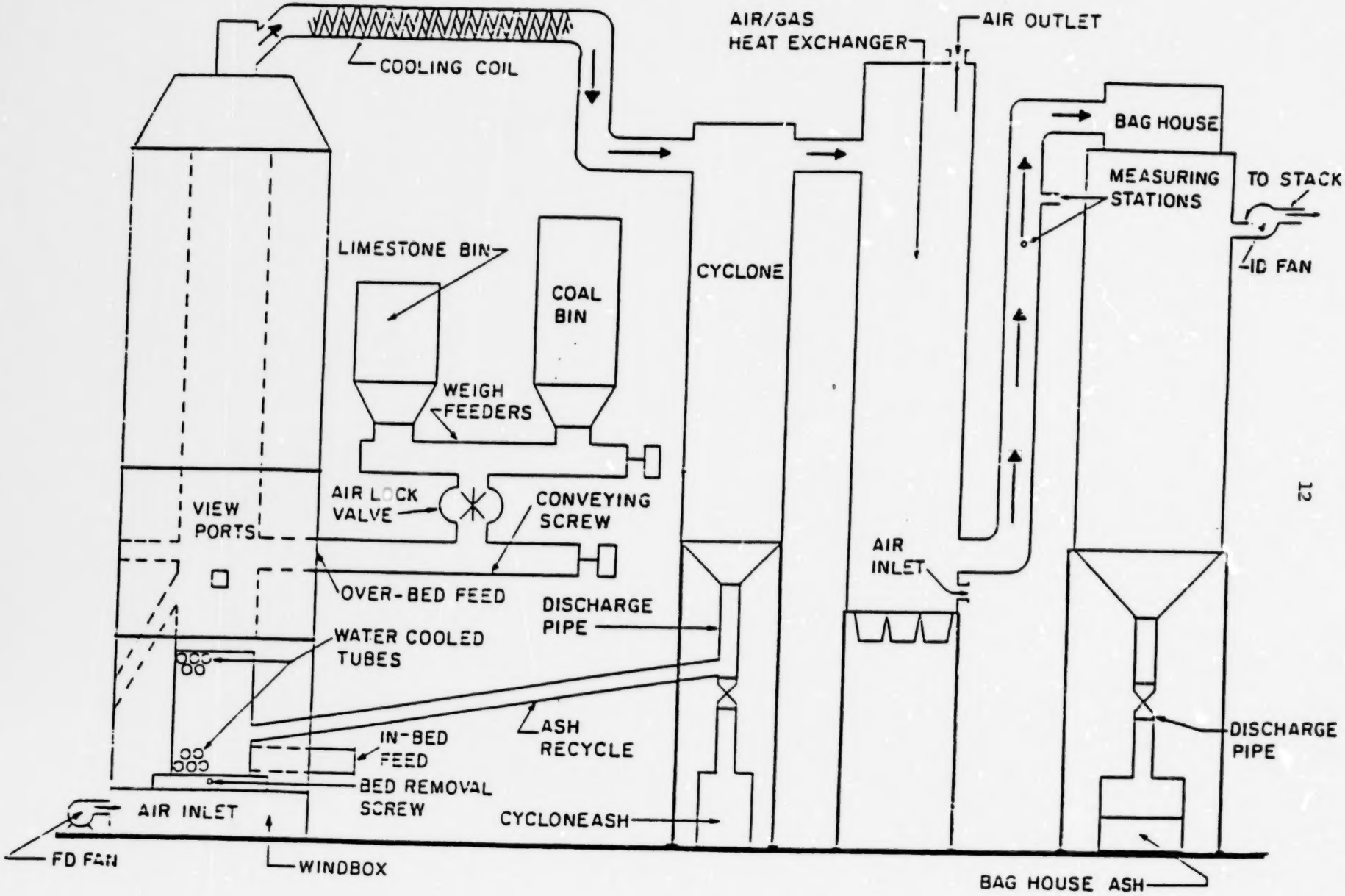

Fig. 1 Schematic of Mark II Fluidized Bed Combustor

Figure 2–CO vs Fluidizing Velocity

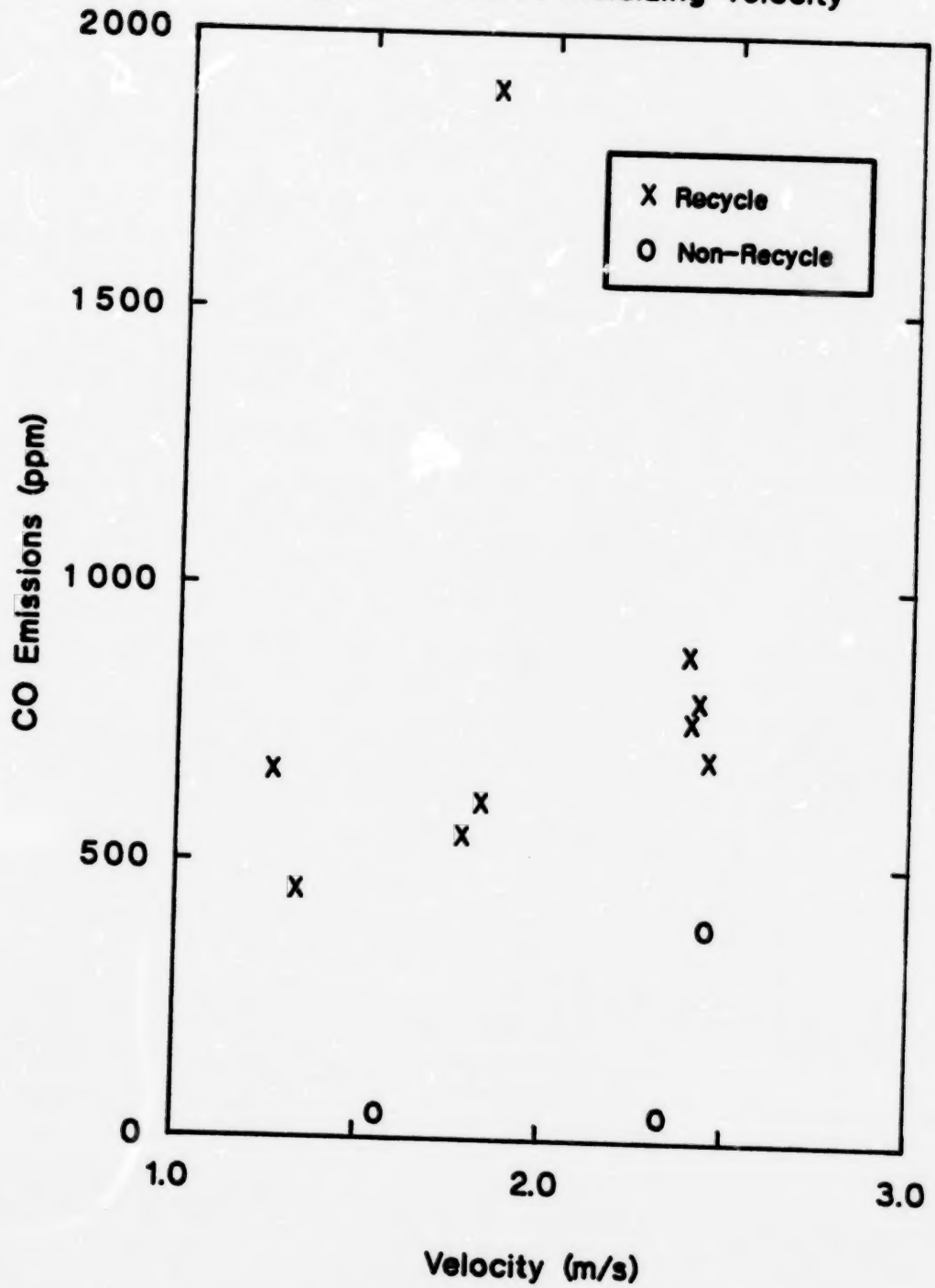

Figure 3–CO vs Combustion Efficiency